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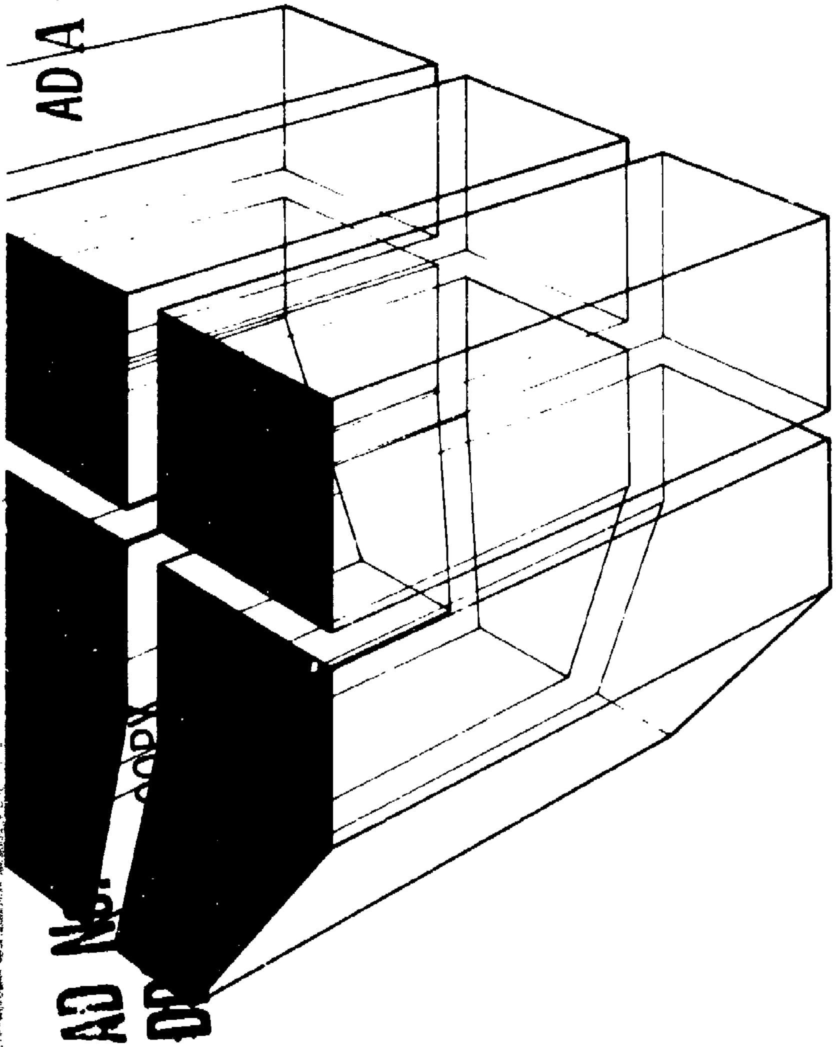
RECOVERY OF ENERGY FROM SOLID WASTE AT ARMY INSTALLATIONS



by
S. A. Hathaway

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This paper provides a technical overview of the current status of solid waste-to-energy conversion systems scaled for use on Army fixed facilities and installations. Attention is given to modular (package) and field-erected heat recovery incineration systems and to using refuse-derived fuel (RDF) in existing steam generation plants. It is shown that most available systems have evolved as an art and not as products of basic scientific inquiry. The proper performance of many marketed systems cannot be guaranteed because neither long term operational data nor reproducible experimental

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information for design exists. Critical research areas in waste characterization, heat recovery incineration, and use of RDF are discussed, and accelerated scientific inquiry within each area is encouraged on a priority basis.

FOREWORD

This paper was prepared for presentation at the Second American Defense Preparedness Association Energy/Environment Conference held March 27-31, 1977, in Kansas City, MO. The work on which this paper was based was performed by the U.S. Army Construction Engineering Research Laboratory (CERL) for the Office of the Chief of Engineers, Department of the Army, under Program Element 6.27.31A, Project 4A762731AT41, "Design, Construction, and Operation and Maintenance Technology for Military Facilities," Task Area T6, "Energy Systems," Work Unit 011, "Refuse-Derived Fuel (RDF) Use."

Dr. L. R. Shaffer is Technical Director of CERL and COL J. E. Hays is Commander and Director.

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FIGURES

FIGURES (cont'd)

RECOVERY OF ENERGY FROM SOLID WASTE AT ARMY INSTALLATIONS

INTRODUCTION

The Facilities Engineer's interest in waste-to-energy conversion systems has been stimulated by the opportunity to conserve costly and scarce conventional fuels, the prospect of conducting waste management operations in a more environmentally compatible manner, the challenge to reduce the costs of installation waste disposal, and the necessity to respond positively to the growing number of laws, regulations, and guidelines bearing upon waste disposal and recovery operations. Favorable publicity in the popular literature describing the large potential payoffs of energy recovery has also provided impetus to program development.[1]

This paper discusses available waste-to-energy conversion technologies thought to have potential installation application, and illuminates major areas where scientific inquiry is encouraged to produce practicable systems. Emphasis is placed on those technologies involving direct combustion as the central conversion process. Technologies considered include modular heat recovery systems, field erected waste-fired boilers, and the use of refuse-derived fuel (RDF) in existing installation-scale central boilers. Initial consideration is given to questions involving characterization of installation waste as it bears upon waste-to-energy conversion systems.

INPUT CHARACTERIZATION

"Input" refers not only to conventional mixed trash and refuse, but to special wastes (pallets, skids, solvents, vehicle lubricant, rubber, cardboard, ADP cards, and paper, etc.) which are generated usually in homogeneous streams at the installation.

Salient characteristics of installation waste include scale and variability. The average installation generates approximately 35 tons (32 mt) of solid waste daily (Figure 1).[2] This is in sharp contrast to daily waste generation rates of 600 tons (545 mt) or more typically found in large cities. The benefit that an Army installation need not collect and dispose of vast amounts of waste is far offset by difficulties in applying most available recovery technologies, which are being developed to meet the needs of large municipalities and do not easily scale down to the dimensions of installation requirements. Adaption of municipal-scale resource recovery technologies is further complicated because installation waste is industrial in nature,[3-7] unlike the input material for which civilian recovery plants are being designed.[8,9] Military solid waste is typically drier, contains more

high calorific value materials, and has a greater heat release rate than civilian municipal-residential waste.

The variability of installation waste takes many forms. The chemical makeup (as measured by heating value and proximate, ultimate, and mineral analyses) of waste at one installation is normally quite different than at another. The daily generation rate, density, condition, and size distribution of the waste vary in a similar manner. This type of variability indicates that a recovery technology sccessful at installation A may be a failure at installation B, which has a similar waste generation rate. Thus, although a downscaled municipal recovery technology might perform satisfactorily at one location, this in no way confirms its potential at another installation generating an equivalent amount of waste.

Also, waste at a single installation is variable with time.[10,11] For example, waste characteristics at place A at time A will usually be different at time B (Figure 2). A recovery technology designed on the basis of a cursory waste survey at one time of the year (sample period A in Figure 3) could well have been differently sized had the design survey been conducted just a few months later (sample period B in Figure 3). Thus, brief waste analyses at the same place but at different times often lead to different conclusions about the potential of an energy recovery program.[12-14] Figures 4, 5, and 6 show combined proximate, ultimate, and mineral analyses of solid waste generated at several different Army and Navy installations in CONUS. The data shown reflect the complex factors which must be taken into account for optimal design. At any time and at any installation, the specific waste chemistry could lie--unpredictably--above or below the range of values shown. Thus, one would not be likely to achieve a properly functioning system on the basis of a chemical analysis of a small waste sample.[15]

It is not surprising, then, that the design of energy recovery systems is more an art than a science. There do not exist comprehensive, practicable procedures by which the Facilities Engineer can develop a reliable waste inventory for resource recovery feasibility assessment.[16-18] Fortunately, the Army has many creative Facilities Engineers who can develop their own input characterization procedures and put them to use effectively. But the possibility is always present that developmental large-scale recovery technologies will be mistaken as proven for small scale applications. Development of improved input characterization procedures and technology scaling methods remain two very deserving areas of scientific inquiry.

MODULAR HEAT RECOVERY SYSTEMS

Modular systems include predesigned, off-the-shelf, highway-shippable components which have a procurement time usually no longer than 8 months. A modular heat recovery line would include the furnace, a package watertube boiler (with appropriate sootblowing and residue

capture capability), air pollution control equipment, stack, and ash removal. The boiler may be equipped with a separate windowbox and burner so it can remain on line after incinerator shutdown. Equipment is usually housed in a pre-engineered building which has sufficient floor area and clearance to accommodate a tipping floor-front end loader waste handling operation. Of central interest are modular incinerators, which, because of size limits for transportation, rarely have rated throughput capacities greater than 1 ton/(0.9 mt/hr) of civilian-type waste.

Modular incinerators are advantageous in that they are less capital intensive than their custom-designed, field-erected counterparts. Their disadvantages, however, are substantial. First, modular incinerators will not accept bulky wastes of the type often found on military installations (Figure 7). If an average waste load can fit easily into the trunk of a large sedan, then most modular incinerator feeders will accept the material. But even nonbulky wastes will not settle evenly in feed hoppers, and all too often rather drastic improvisations are required to compact the material (Figure 8).

Second, because modular incinerators are predesigned for municipal rather than military waste, which has a significantly higher heat relase rate, they must usually be derated by up to 30 percent. Hence, the average Army installation, which generates 35 tons/day (32 mt/day) of solid waste, would require a plant processing capacity of at least 50 tons/day (45 mt/day) just to allow for derating. To process waste on a one-shift basis (6.5 hours effective burn time), this installation would require an installed hardware capacity of about 8 tons/hour (7.2 mt/hour). The plant would therefore require a minimum of eight units rated at 1 ton/hour (0.9 mt/hour) operating in parallel. Since each unit must be fed every 7.5 minutes,[19] the plant operator would have to load each incinerator feeder in less than 1 minute to sustain optimal use and total plant performance.

One approach to the derating problem has been to install a water spray either at the feeder or within the furnace itself. It is speculated that quenching the waste lowers its heat release rate, makes the mass throughput capacity of the furnace more controllable, and extends the load cycle time. However, this approach contradicts one essential objective of heat recovery incineration, which is to use heat liberated economically through combustion in a furnace to evaporate water to steam in a controlled downstream heat exchanger--not to wet down the charge and evaporate virgin water in the furnace. Higher than necesary combustion heat losses and lower than desirable system efficiency and economy are inescapable consequences of this measure.

Another frequently encountered combustion problem stems from the advice given by some manufacturers to operate modular incinerators at furnace temperatures in the neighborhood of 2200°F (1204°C). Stationary bed incinerators (Figure 9) are particularly prone to severe slagging at temperatures above 1800°F (982°C), where the viscosity of refuse ash

(particularly glass, ceramics, ferro-aluminum compounds) is in the plastic range. An expected result is accelerated refractory wastage. Attendant operational problems include plugging of underfire air ports, bed channeling, and incomplete combustion. Even at lower operating temperatures, it is not unusual for some units to require manual ream-out of frequently inaccessible underfire air ports several times during an operating shift.

A third major disadvantage of modular incinerators is their questionable durability, which has spawned divergent approaches toward their use on Army installations. The first approach is to protect the combustor, either by installing redundant furnaces and alternating operation or by processing the waste (shredding, magnetic removal of ferrous metals, screening for removal of glass and other inerts) before it is fired. If the processing alternative is selected, the waste will gain a substantial value added before it enters the furnace, and the plant will require additional skilled operating personnel and control and safety systems. The second approach is to fire as-received waste (with oversized bulky incombustibles removed), perform the minimal maintenance required to keep the unit reasonably operational, and repair by replacement when the rising cost of minimal maintenance so warrants. It is not known which approach toward solving the durability dilemma is more appropriate, because operational data on these developing systems are just beginning to accumulate.

Nor are vital parameters known which permit accurate economic and value analyses of modular incinerators. Routine O&M requirements, cyclic maintenance requirements, and length of economic life are currently only speculative. An often travelled path around the latter factor is to assume that a modular system will last a specified period of time, usually 20 years. This assumption has been so widely proliferated that, despite the absence of any substantiative data, it is being increasingly and dangerously considered a fact.

The controlled air incinerator is presently the most widespread of the four major modular incinerator configurations. It is a stationary bed furnace which is semi-continuously fed by a hydraulic ram feeder. The controlled air incinerator may have a "piggybacked" secondary chamber of equal size to the primary chamber (Figure 9), or may consist only of a primary combustion chamber and a small afterburning volume immediately after (Figures 10 and 11). In one modular incinerator resembling the controlled air unit, ash is discharged through refractory-lined bomb bay doors which close to form the floor of the furnace. In the more conventional systems, ash is removed by positive displacement out the bottom of the primary chamber. Throughput ratings for municipal waste rarely exceed 1 ton/hour (0.9 mt/hour), meaning that the average Army installation may require up to 16 controlled air units installed in parallel, depending upon operating hours per day and the approach taken to the durability problem discussed above.

In addition to the general problems reviewed above, operational troubles with the controlled air incinerator concern controls, ash handling, and construction. At one formerly operating $2 million facility (with no heat recovery equipment), a bypass damper was installed in refractory-lined breeching between the furnace and the air pollution control apparatus (a modular fiberglass wet scrubber). The damper was to divert combustion products to the stack upon initiation of furnace cooldown. When a piece of refractory waste jammed the damper in its nondiverting position, the control system indicated positive bypass and automatically shut down scrubber water supply. Hot gases continued to enter the scrubber, and the resulting fire caused substantial equipment and structure damage. Provision of an inexpensive limit switch could have prevented this loss. At this facility and others, burnout of undersized motors has been a problem. Many ram feeders show a tendency to withdraw pieces of burning waste on their backcycles, exposing plant personnel to smoke and threat of widespread fire. It is not unusual for proper operation of some controlled air incinerators to rely on controls that can easily be overriden. At one facility equipped with a temperature-set quench as a combustion control, the operator disconnected the overtemperature control system to inhibit spray activation. The result was partial burnout of the afterburner housing (Figure 12). At yet another facility, ash is removed from a quench by inclined drag conveyor. Bulky materials frequently collect and jam at their withdrawal point, which has resulted in numerous episodes of shear pin failure, with the breaking pine launched across the operating floor at hazardous velocities.

The rotary kiln is an inclined rotating furnace which, with some modification, has had some munitions demilitarization applications. The general concepts underlying operation of the rotary kiln modular incinerator are shown in Figures 13, 14, and 15. While the controlled air incinerator has a 2.5-year history in small city heat recovery operations, the rotary kiln has no such record. It is theoretically superior to the controlled air configuration in that it mechanically mixes the burning material. But, as with the controlled air unit, bulky incombustible materials jam at the ash pass and result in unit outage until manually removed. The rotary kiln furnace is about three times more costly than the controlled air configuration ($450,000 vs $150,000 procurement cost).

Two of the four basic modular furnace configurations have only recently been developed. The basket grate (Figure 16) is a continuously fed, inclined rotating cone-shaped grate which has yet to completely demonstrate its capabilities in energy recovery. Two operational problems of major significance are the tendency of incombustibles to collect in and reduce the effectiveness of the furnace volume, and the tendency of fine combustibles to sift through the grate while still burning (Figure 17). The augered bed incinerator resembles the controlled air in appearance (Figures 18 and 19); however, waste is conveyed through the furnace by a water-cooled spiral flight. While the

basket grate is rated at 3 tons/hour (2.7 mt/hr) capacity, the augered bed incinerator claims an hourly throughput capacity of 5 tons (4.5 mt). Like the basket grate, use of the augered bed incinerator in CONUS is limited to a single operating prototype, and few conclusive performance data are available.

The encouraging aspect of both the basket grate and augered bed incinerators is that they are attempts to provide greater throughput capacities in modular, low-cost packages. With a reliably operating augered bed incinerator, the average installation could process all its solid waste in one shift per day. Reduced labor requirements alone argue persuasively in favor of further developing and applying such promising technologies.

REFUSE-DERIVED FUEL (RDF)

The rationale for using RDF is based on economic tradeoff: is it less costly to process waste into RDF for use in an existing boiler, or is it more cost-effective to install new combustion equipment to fire a less-processed waste? At present, RDF is highly developmental, and its most immediately foreseeable use is as a 10%-20% supplement (by as-fired heating value) in pelletized form with coal in central boilers equipped with traveling chain grate or spreader stokers. To date, some boiler tests have been performed,[20-22] and there is reason for tempered optimism. Unfortunately, however, many experiments have not produced the quality of design-type data required to support engineering feasibility studies at other locations.

There are as many suggested ways to produce DRDF as there are individuals who have an interest in producing it.[23-26] This is essentially because DRDF production is still more an art than a science. Few data are available to support rational argument for--or against--any particular process,[27] but it is commonly agreed that any process will include multiple shredding stages, air classification, screening, drying, and pelleting. One process flow is shown in Figure 20,[28] and its products--predensified "fluff" RDF and DRDF--are shown in Figures 21, and 22, respectively. The fluff RDF shown is similar to the material currently cofired in suspension with pulverized coal in Union Electric Company's utility plant in St. Louis, MO.[29]

Recent work has shown that for every unit of waste put into a DRDF production line, between 0.4 and 0.5 units of DRDF will be produced.[30] Hence, between 0.5 and 0.6 units will appear as process rejects (this includes dust, true reject waste, and some potentially recyclable materials). These materials remain a handling and disposal requirement. The average installation generating 35 tons/day (32 mt/day) of solid waste would be fortunate to realize half that mass as DRDF. And, since at least half its waste stream would remain a disposal requirement, there would likely be at best only negligible reduction of its waste disposal costs.

The true economy of DRDF production is still largely speculative. It has been shown that a plant with a daily input of 100 tons (91 mt) can produce DRDF at a per ton input cost between $10 and $12,[31] excluding reject handling, amortization of the $2.3 million equipment and building investment, and delivery to and handling of DRDF at the using point. But the capital use factor is well below 0.20 for a one-shift operation because of high preventive maintenance requirements and low total system reliability.

There are many points in the DRDF spectrum which offer challenges to the engineer and scientist. Many waste processing facilities have poorly designed materials handling facilities, with attendant housekeeping problems and avoidable excess labor (Figure 23). Such plants are often symptomatic of the art-not-science approach to waste processing, in which modular off-the-shelf equipment is used in an application for which it was not designed.

While progress is being made toward producing a DRDF that will handle like coal, there are still no convincing data to indicate that the waste fuel pellet will not structurally deteriorate when subjected to normal coal conveyor vibration (Figure 24), and even under moderate load in coal storage bunkers. Recent research into the mechanical properties of DRDF and DRDF/coal mixtures has indicated that most coal handling and storage systems will require redesign to reliably handle the bulk solids which they were not originally intended to accommodate.[32] Because of its unique properties, DRDF is not prone to coal type gravity mass flow (Figure 25) from storage bunkers, but instead will exhibit at best funnel flow (Figures 26 and 27) and most probably no flow at all. In the latter case, the fuel cannot be easily removed from its storage vessel by any means. Indeed, under agitation, the rate of structural deterioration of the pellet is increased, and the fibrous material becomes even more dense and immovable.

However, it should be noted that certain types of DRDF may flow from some existing coal storage bunkers.[33] Nearly all military coal storage vessels were fabricated and installed as long as 40 years ago, when their design was based upon experience and informed engineering intuition. Only recently has a scientific approach been taken toward storage and flow of bulk solids which considers their dynamic properties in storage vessels.[34] Thus, some existing bunkers handle their coal well, while others do not. While some of these bunkers might also successfully handle DRDF and/or DRDF/coal mixtures, this appears to be attributable to good luck, and the available data are not the type on which contemporary engineering design is customarily based.

Similarly little scientific research has been performed on the behavior of DRDF in a boiler. We know that DRDF has a lower calorific value and ignition temperature than nearly all coals, and usually burns with a cooler and larger flame. We also know that it has a much more

rapid rate of reaction than coal. The facts argue convincingly that if the boiler is to be kept at rated capacity when firing DRDF, the furnace volume must be considerably enlarged (Figure 28).

It is not easy to pin down the combustion behavior of DRDF to make conclusive assessments about the feasibility of its use. Many standard testing methods successfully used for coal characterization fail when attempts are made to similarly analyze DRDF. The American Society for Testing and Materials has recognized this problem, and its Energy Subcommittee is currently developing RDF testing procedures.[35]

Despite the fact that essentially the same kind of input characterization problems plague the use of DRDF as hinder proper incinerator design, general studies continue to assert that DRDF is easily usable in substantial numbers of Federal boilers.[36] Such studies often take for granted that established boiler coal feeding equipment will perform adequately with DRDF. However, the types of flow problems encountered with DRDF in existing coal bunkers may be anticipated in attempts to pass the waste fuel through the conventional weigh larry (Figure 29) in travelling grate applications or the standard mechanical feeder in spreader stoker systems (Figure 30).

It is generally accepted that a DRDF production line will include multiple shredding stages, air classification, screening, drying, and pelleting. Few appliances used in any currently operating system have been designed to process variable solid waste, but rather have been adapted from other industrial applications. It is currently better known what most equipment does rather than why it works (or doesn't) on solid waste.[37] Processing plants often contain a nearly randomly sequenced range of poorly selected, adequate, and brilliantly designed equipment, with the aggregate result of nonoptimal system reliability, controlability and predictability. The proper performance of many systems depends upon skilled labor with qualifications both to operate advanced and adapted equipment and to innovate quick, artful changes in the process to obtain desired output. To guarantee smooth operation of such plants for an acceptable economic life is highly risky. The high degree of complexity in using DRDF is exceeded only by the magnitude of the challenge with which the problem confronts the engineer and scientist. In either case, vigorous scientific inquiry is needed and should be encouraged.

FIELD ERECTED SYSTEMS

These systems (Figure 31) are usually more reliable than those reviewed above. Data from plants such as the Naval waterwall incinerator in Norfolk, VA, are beginning to lead to improved plant designs. Operational data from modern plants indicate that shredding of delivered waste is being recommended more often to improve furnace performance (Figures 32 and 33).

The theoretical advantages of shredding are numerous. It loosens and reduces the waste to a smaller and more easily handleable particle size range,[38,39] increases the charge's surface/volume ratio and hence improves its combustion performance, ballistically rejects many bulky incombustibles which adversely affect combustor material, and by mixing makes the charge somewhat less variable than its unprocessed feedstock.[40] But along with shredders come the disadvantages of plant problems in maintenance, reliability, materials handling, and safety.

A variety of relatively short-term shredder maintenance data exists,[41] and indications are that complete overhaul must be done as much as 12 times annually, that most hammers on hammermills must be replaced after 400 to 1000 tons (363 mt to 908 mt) have been processed, and that hammer hardfacing or tip rewelding must be done daily (Figure 34). The latter task requires about 4 hours per shredder. Cyclic maintenance requirements are not fully known. In the case of hammer replacement, worn hammers must ordinarily be disposed of, since most are made of specialized hardened steel which has no use in the current salvage market.

Reliability of shredders is very speculative. It is not unusual for unforeseeable downtime to last several weeks until special replacement parts are made, delivered, and installed, and the unit is tested. Shredder explosions are not infrequent and, aside from unit outage, endanger plant personnel. Explosions may be caused by a variety of phenomena, including discarded explosive materials in the waste, presence of volatiles such as solvents and gasoline, and ignition of suspended dust by sparks generated when the hammers strike other metallic objects in the feed. Despite the well-publicized dangers of shredders, many processing plants persist in stationing personnel (such as pickers to remove adverse materials from the feed conveyor) close to the units. Some plants have installed acoustic/blast partitions around shredders, with breakaway panels in the roof to accept the forces and shrapnel liberated by the explosion.

Other hazards involving shredders are dust (including airborne bacteria and viruses) and fire. Modern plant designs include an air hood near the shredder to prevent a dangerous concentration of dust near the unit.[42] Despite the obvious possibility of fire spreading rapidly throughout the waste processing system, many designs neglect adequate fire protection, either in the form of special construction, a quench system, or clearly marked personnel escape routes.

Although the disadvantages associated with shredding are numerous and serious, at the current state of the art, neither the disadvantages nor the advantages (in the form of improved combustor performance) can be quantified in a cost-benefit manner to provide a basis for decision making.

Other problems revealed in the field erected systems which are not apparent in most large incinerator plants include sanitation and pest control. It is prudent to plan a sufficient budget for these items.

Scientific research has brought us improved firing and stocking methods, so that the double reciprocating grate (Figure 35) is now preferred over the conventional traveling grate (Figure 36) and other configurations.[43] This advanced stoker will be installed at Ft. Monmouth, NJ, where purchased shredded RDF will be fired in a converted boiler. The frequent and costly grate burnout problems encountered with conventional traveling grates (necessitating bar replacement as often as once a week) will probably be far reduced.

Despite advances in stoking mechanisms, it is still not uncommon for severe problems to occur when a technology workable at one location is transferred to another. One recently built municipal waste incinerator is equipped with a stoker configuration having relatively long operational success in Europe. But European refuse is wetter, contains fewer high calorific value materials, and has a lower heat release rate than the waste in the U.S. city where the stoking technology was adapted.[44] As a result, to protect the maladapted stoker from severe thermal damage, a water spray had to be installed near the incinerator feed throat. The plant continues to operate with lower than desired efficiency and still experiences numerous operational difficulties.

For Army-scale operations, it is preferable to employ a front-end loader handling system instead of the less reliable pit-and-crane system wherever possible. Front end loaders have been proven capable of moving as much as 650 tons/day (590 mt/day),[45] indicating their potential applicability even in large regional waste management operations. The recommended loader is propane-fueled, with filled tires.

When designed properly, field erected systems will function in a way far superior to modular incinerators and DRDF at the current state of the art. This is not to say there are no challenges. Areas of unknowns include slagging potential,[46] grate fouling, corrosion,[47] if and how to shred,[48] how to cope with the variability of input material in design and practice,[49] and combustion control methods.[50] There is also a need for economic data to provide a sound base for life cycle and value analyses in assessing the feasibility of applying a similar technology elsewhere.[51-54]

CLOSURE

The goals of recovery programs set forth in the Introduction are critically important, and perhaps no one knows this better than the Facilities Engineer. He is acutely aware that by reducing the resources allocated to waste disposal/recovery and energy production operations, equivalently more resources can be made available for more direct support of the defense-oriented mission of the installation, and ultimately, of the soldier. This is what he is working for, and it is the business of the responsible engineer and scientist to support him in this effort.

There is no question that the future holds great promise for recovering energy from installation solid waste. But at present there exists no small-scale energy recovery technologies which can be implemented with guarantee of predictable, trouble-free operation. Some currently promoted systems might perform adequately, but many more will do little but consume valuable resources that better could be put to use elsewhere.

That the majority of currently operating energy recovery systems do not perform dependably does not reflect "shortcut" engineering, but instead underscores the absence of the design data necessary to create a p cticable facility. An important goal of the research engineer's work is to develop systems based on a firm foundation of scientific fact and not a resource-intensive, hit-and-miss approach. The goals of recovery programs provide sufficient motivation for accelerated scientific research and development, and the time to proceed is now.

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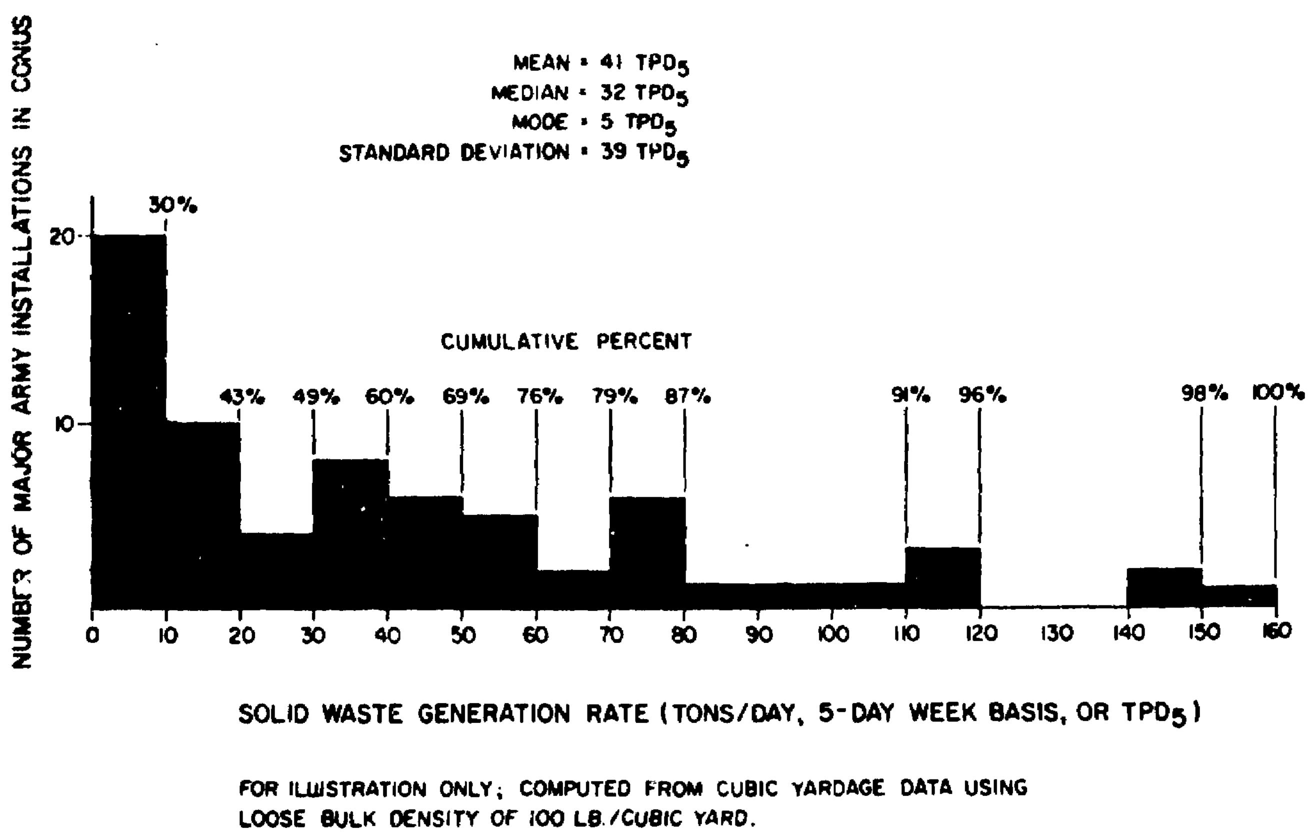


Figure 1. Scale of Army Installation Solid Waste Generation Rate. The average installation generates about 35 tons (32 mt) of mixed trash and refuse daily.

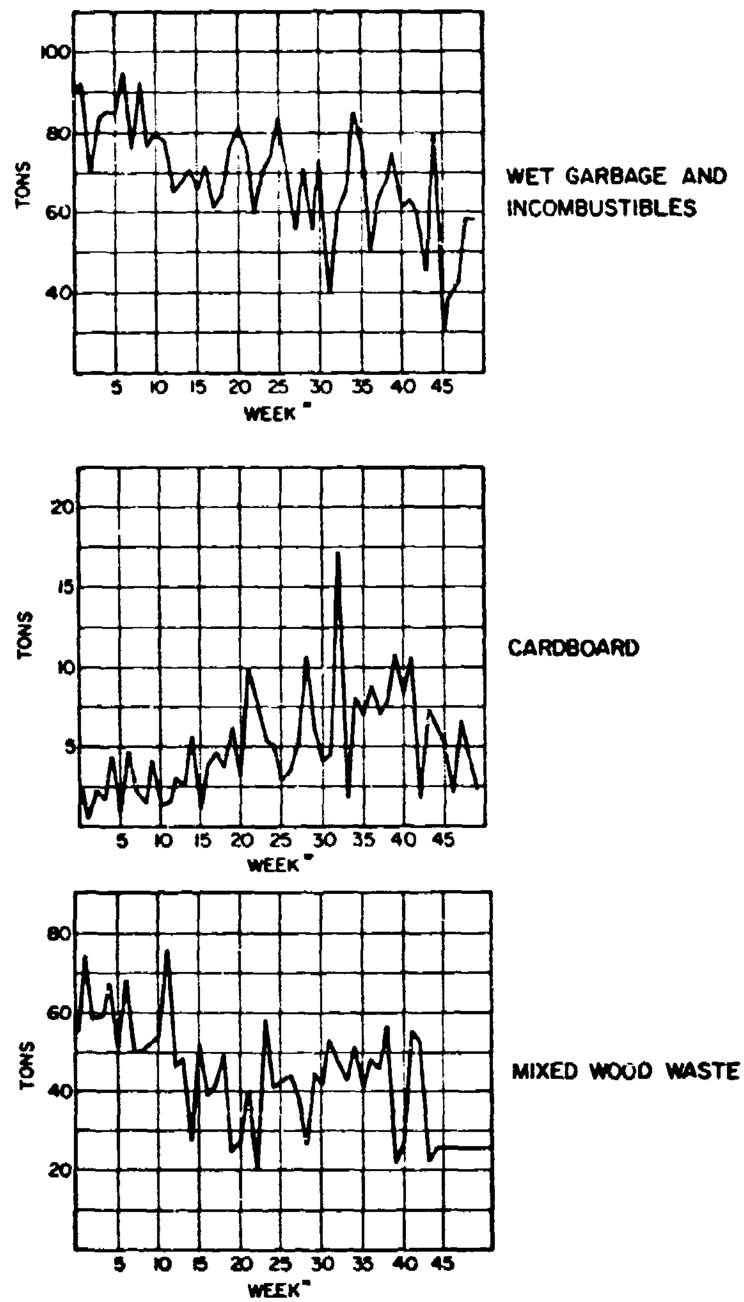


Figure 2. Time-variability of Solid Waste Composition at an Army Installation. A waste survey during week 15 would yield different conclusions about resource recovery than would a survey in week 32.

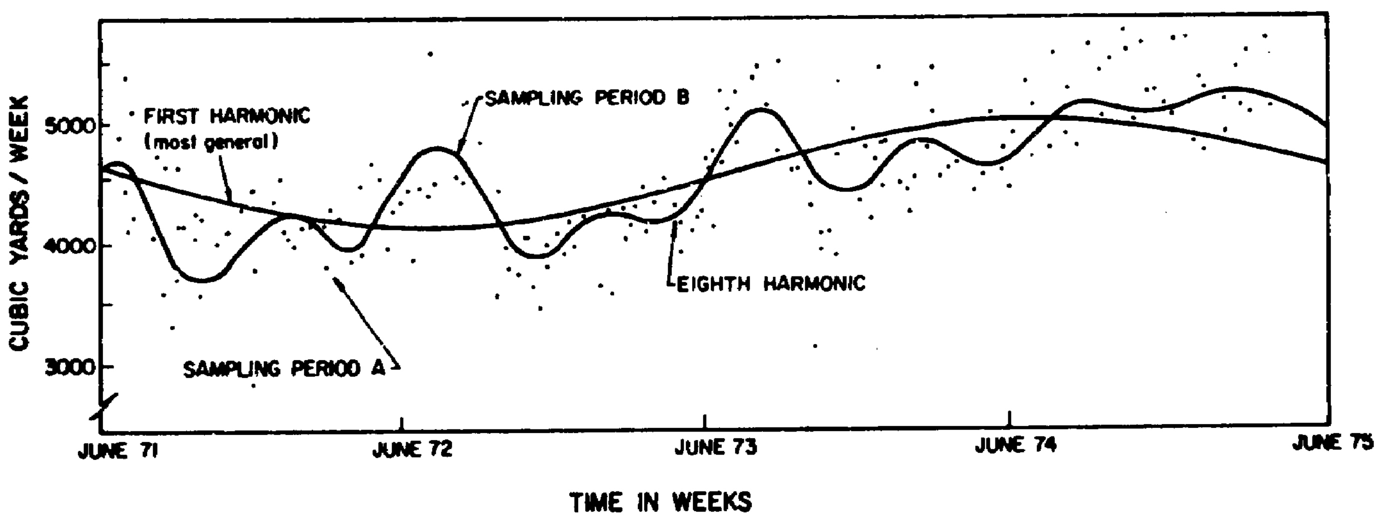


Figure 3. Time-variability of Installation Solid Waste Generation Rate. A resource recovery facility sized on the basis of data from sampling period A would be different from one sized according to data from period B.

	SOLID WASTE (%)	ABSOLUTE VARIATION (%)
MOISTURE	16.69 —— 31.33	14.64
ASH	9.43 —— 26.83	17.40
VOLATILE	25.75 —— 38.90	13.15
FIXED CARBON	0.61 —— 14.64	14.03
AS-FIRED HEATING VALUE	3900-5505 Btu/lb	1605 Btu/lb

Figure 4. Chemical Variability of Installation Waste Is Reflected in Range of Values for Proximate Analysis.

	SOLID WASTE (%)	ABSOLUTE VARIATION (%)
MOISTURE	16.69 — 31.33	14.64
CARBON	23.45 — 33.47	10.02
HYDROGEN	3.38 — 4.72	1.34
NITROGEN	0.19 — 0.37	0.18
CHLORIDES	0.13 — 0.32	0.19
SULFUR	0.19 — 0.33	0.14
ASH	9.43 — 26.83	17.40
OXYGEN	15.37 — 31.90	16.53

Figure 5. Chemical Variability of Installation Wastes Is Reflected in Range of Values for Ultimate Analysis.

	SOLID WASTE (%)	ABSOLUTE VARIATION (%)
PHOSPHORUS PENTOXIDE	1.02 — 4.69	3.67
SILICA	48.93 — 60.07	11.14
FERRIC OXIDE	3.50 — 5.92	2.42
ALUMINA	5.02 — 13.72	8.70
TITANIA	0.74 — 1.60	0.86
LIME	7.54 — 18.19	10.64
MAGNESIA	1.14 — 1.91	0.77
SULFUR TRIOXIDE	1.84 — 12.54	10.70
POTASSIUM OXIDE	1.57 — 2.70	1.13
SODIUM OXIDE	3.62 — 5.95	2.33
UNDETERMINED	0.08 — 0.69	0.61

Figure 6. Chemical Variability of Installation Waste Is Reflected in Range of Values for Mineral Analysis.

Figure 7. Typical Military Bulky Wastes. Package incinerator feeders will not accept such material, necessitating shredding or separation.

Figure 8. Laborer in Recently Built Package Incinerator Plant Compacting the Charge to Permit Ram Feeder Operation. Misapplied hardware often requires compensating steps which jeopardize plant personnel.

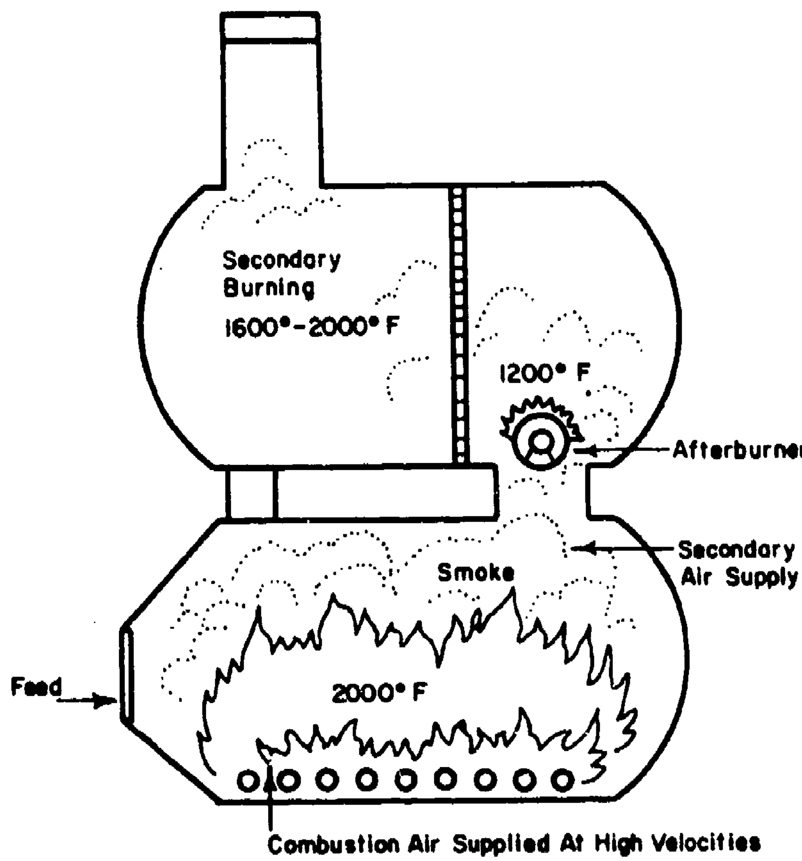


Figure 9. Controlled Air Incinerator (First Major Configuration). Stationary bed furnace has throughput capacity no greater than 1 ton/hour, and must often be derated.

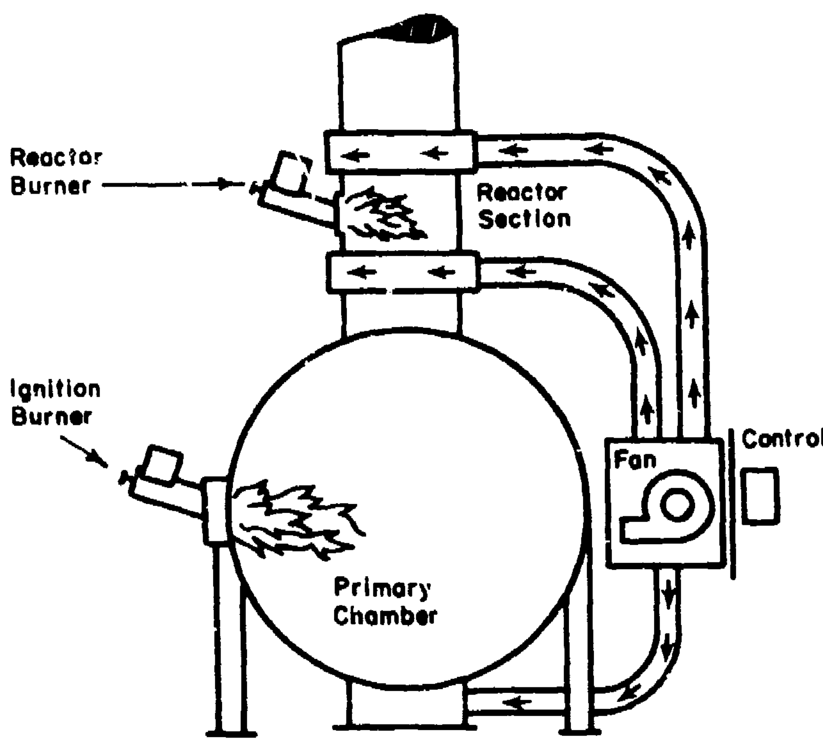


Figure 10. Controlled Air Incinerator (Second Major Configuration, Front View).

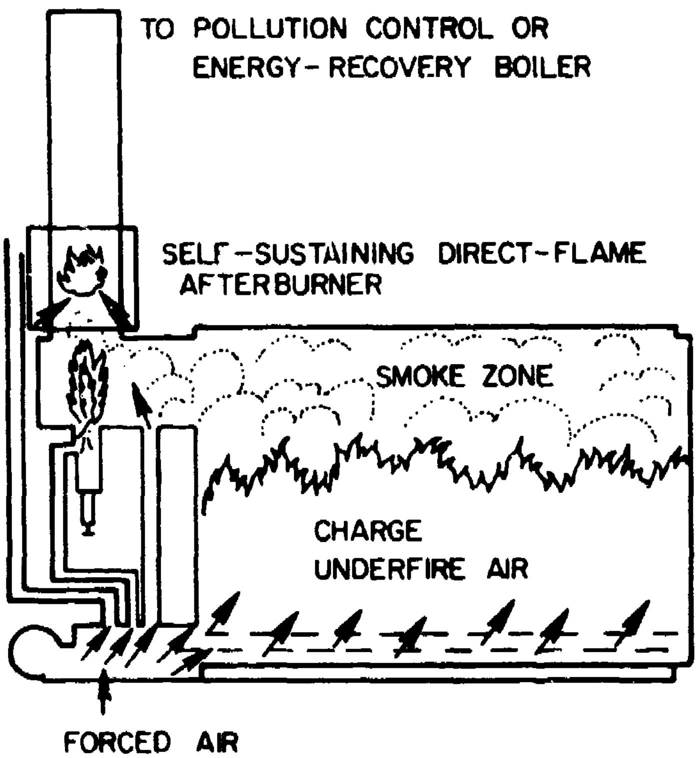


Figure 11. Controlled Air Incinerator (Second Major Configuration, Side View).

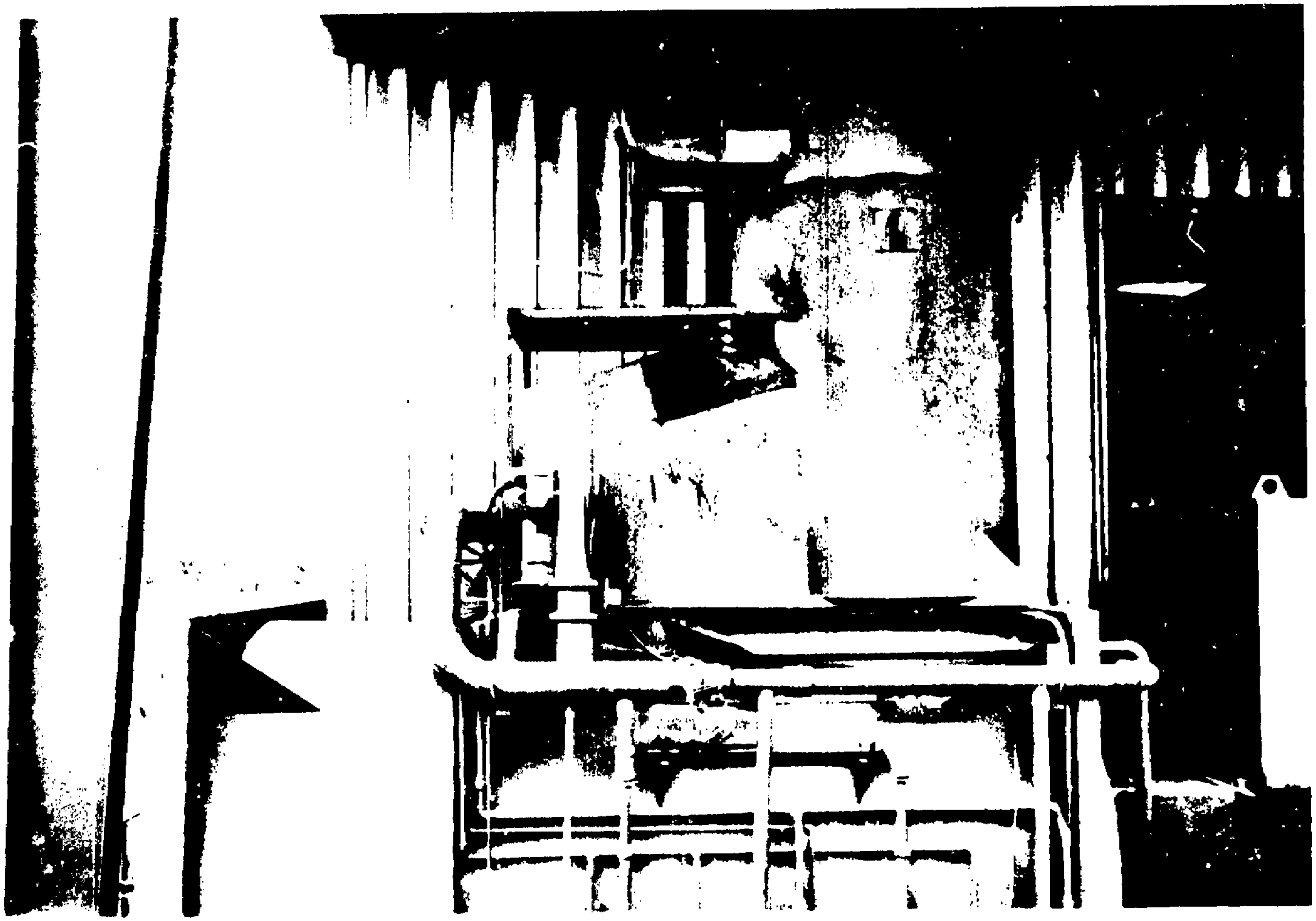
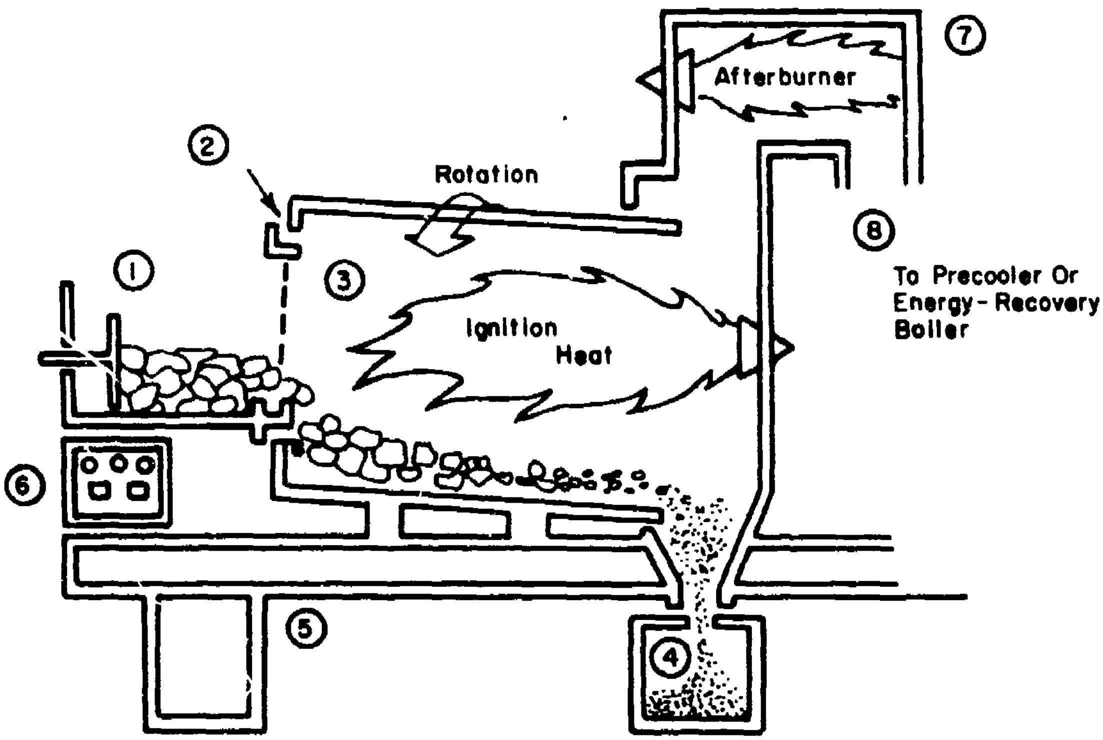


Figure 12. Burnout of Afterburner Housing in Controlled Air Incinerator. Combustion controls can often be overriden, resulting in capital damage.



1 Coarse RDF Auto-Feed (Hopper, Pneumatic Feed, Slide Gates)
2 Forced Air
3 Refractory-Lined Rotating Cylinder (Primary Chamber)
4 Ash Hopper (Incombustibles)
5 Support Frame And Piers
6 Control
7 Secondary Chamber
8 To Appurtenances

Figure 13. General Operation of Rotary Kiln Package Incinerator.

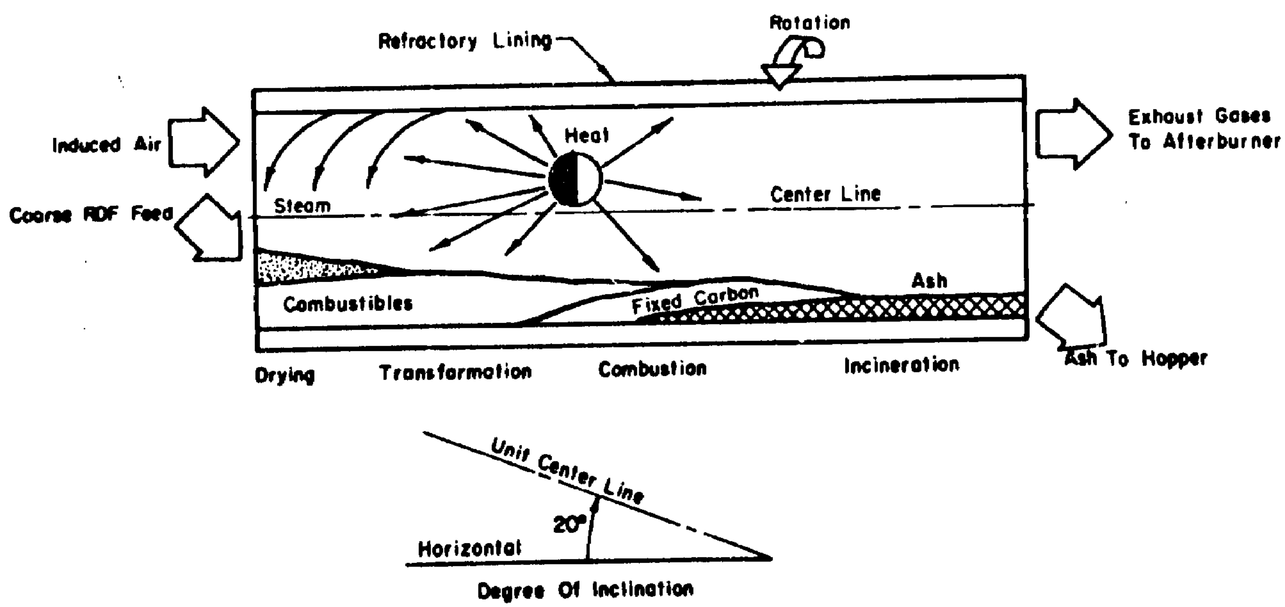


Figure 14. Combustion in Rotary Kiln Package Incinerator.

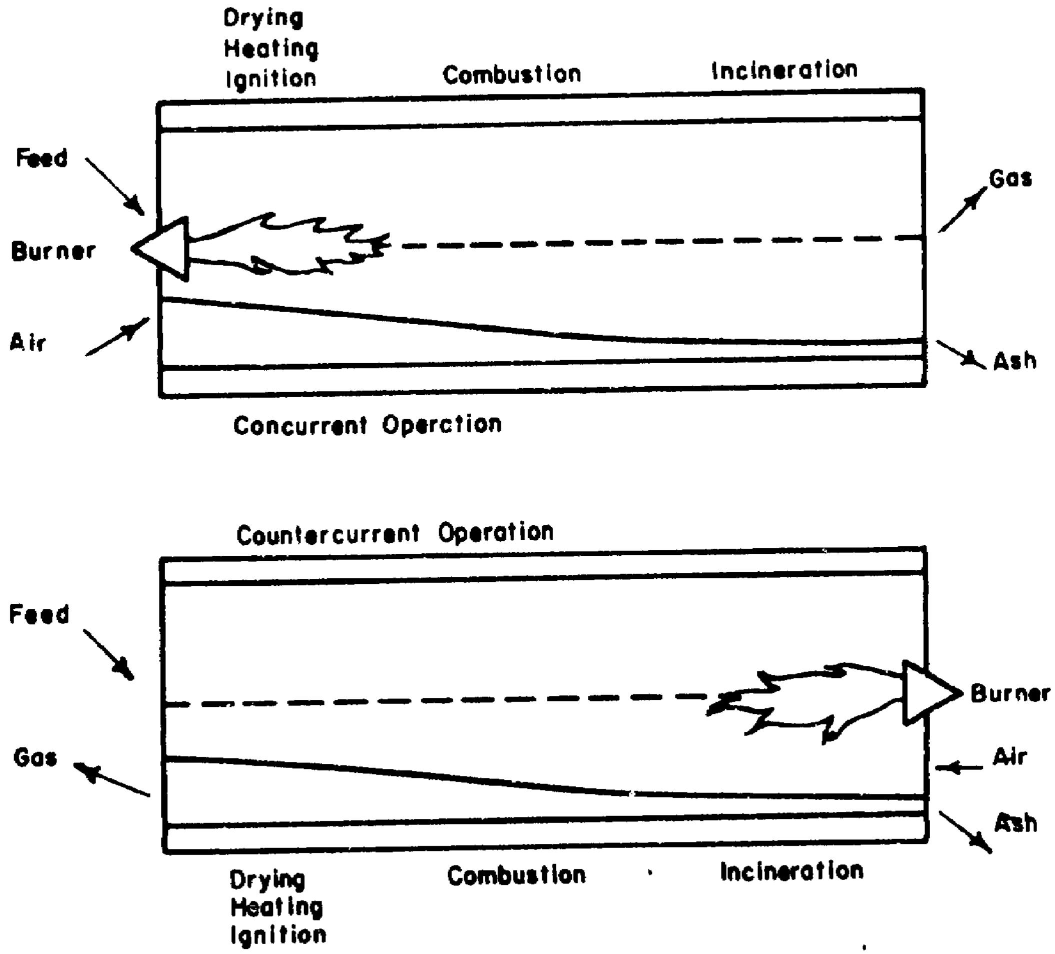


Figure 15. Concurrent and Countercurrent Operation of Rotary Kiln Package Incinerator.

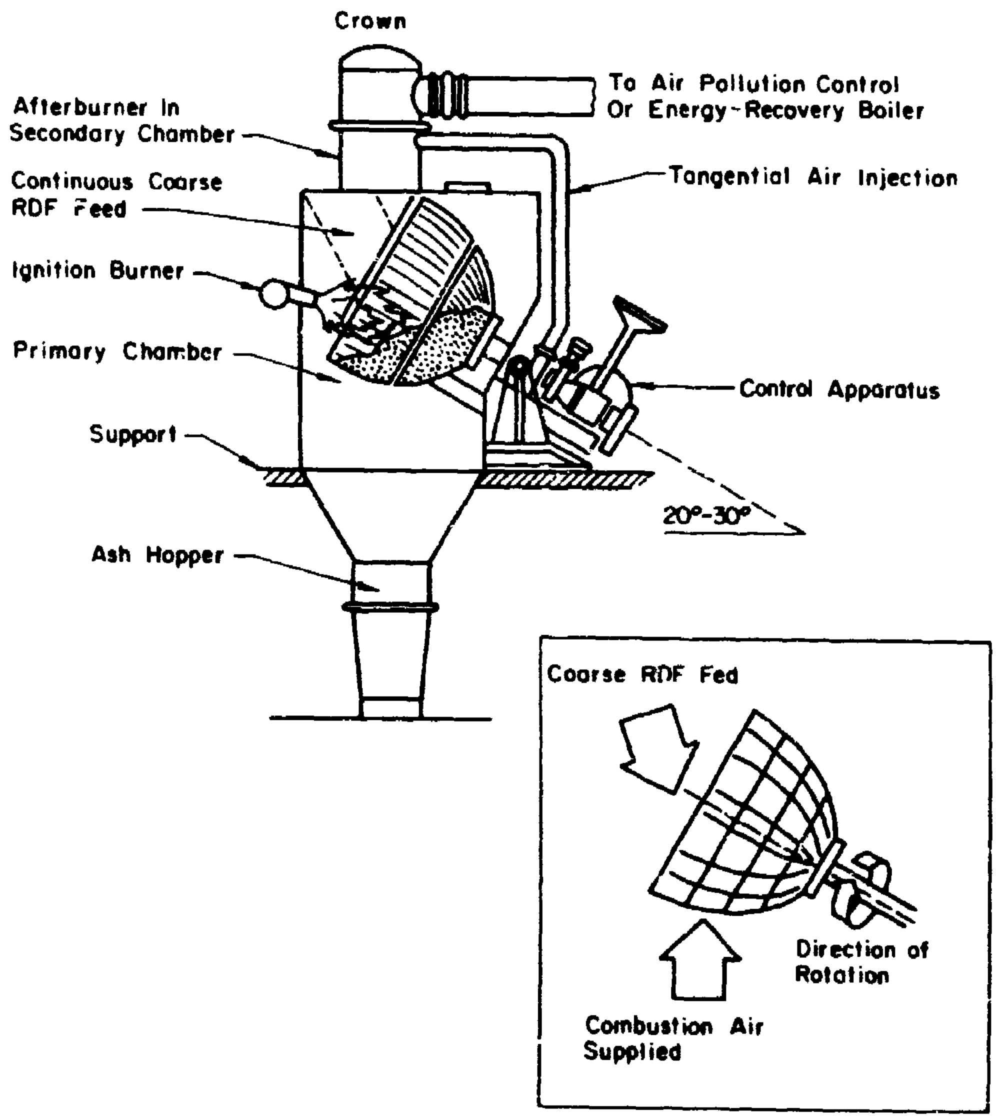


Figure 16. General Operation of Basket Grate Package Incinerator.

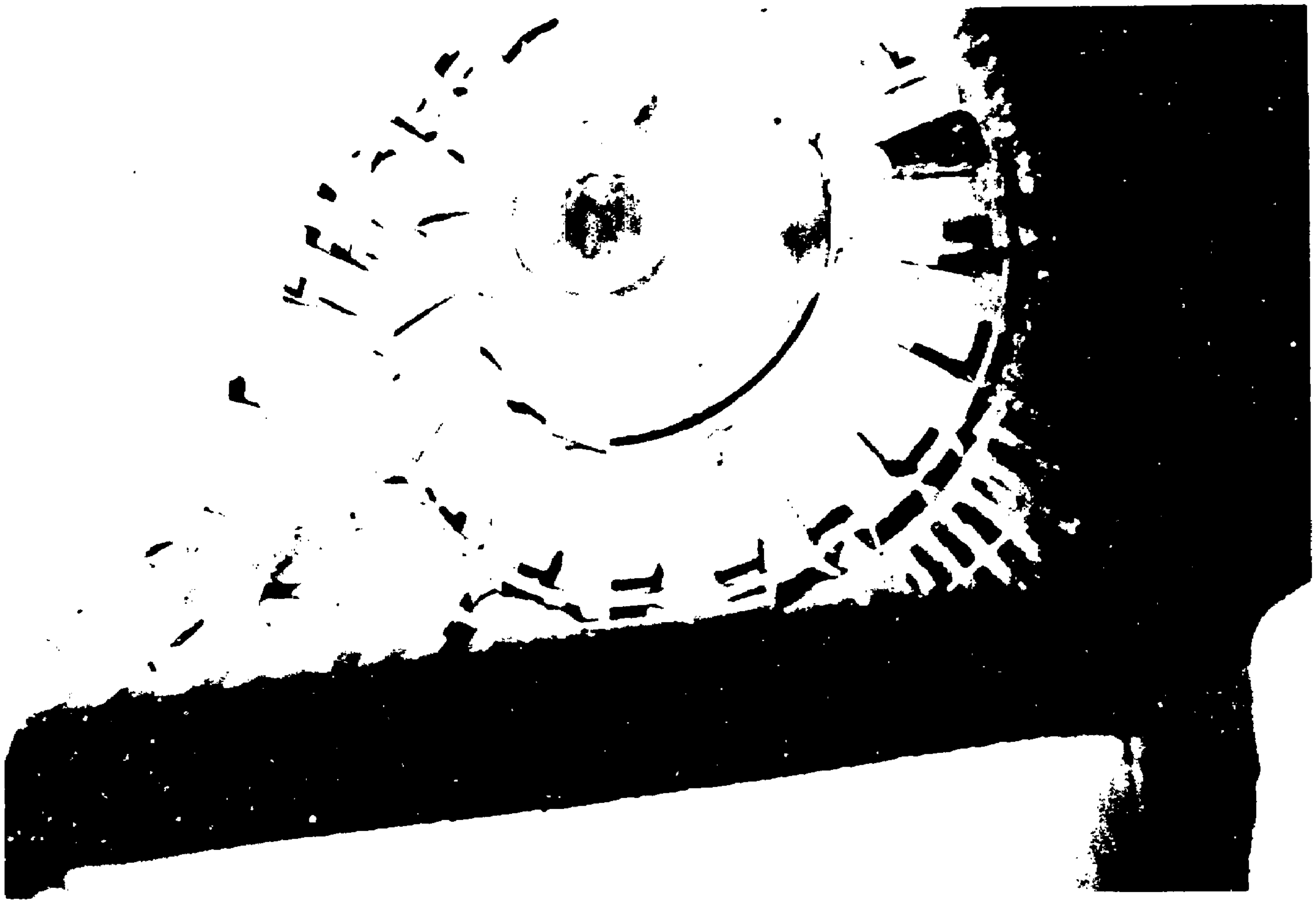


Figure 17. Grate Configuration in Basket Grate Package Incinerator. Bulky combustibles can accumulate, reducing furnace volume. Fine combustibles sift through grate and burn in ash hopper below.

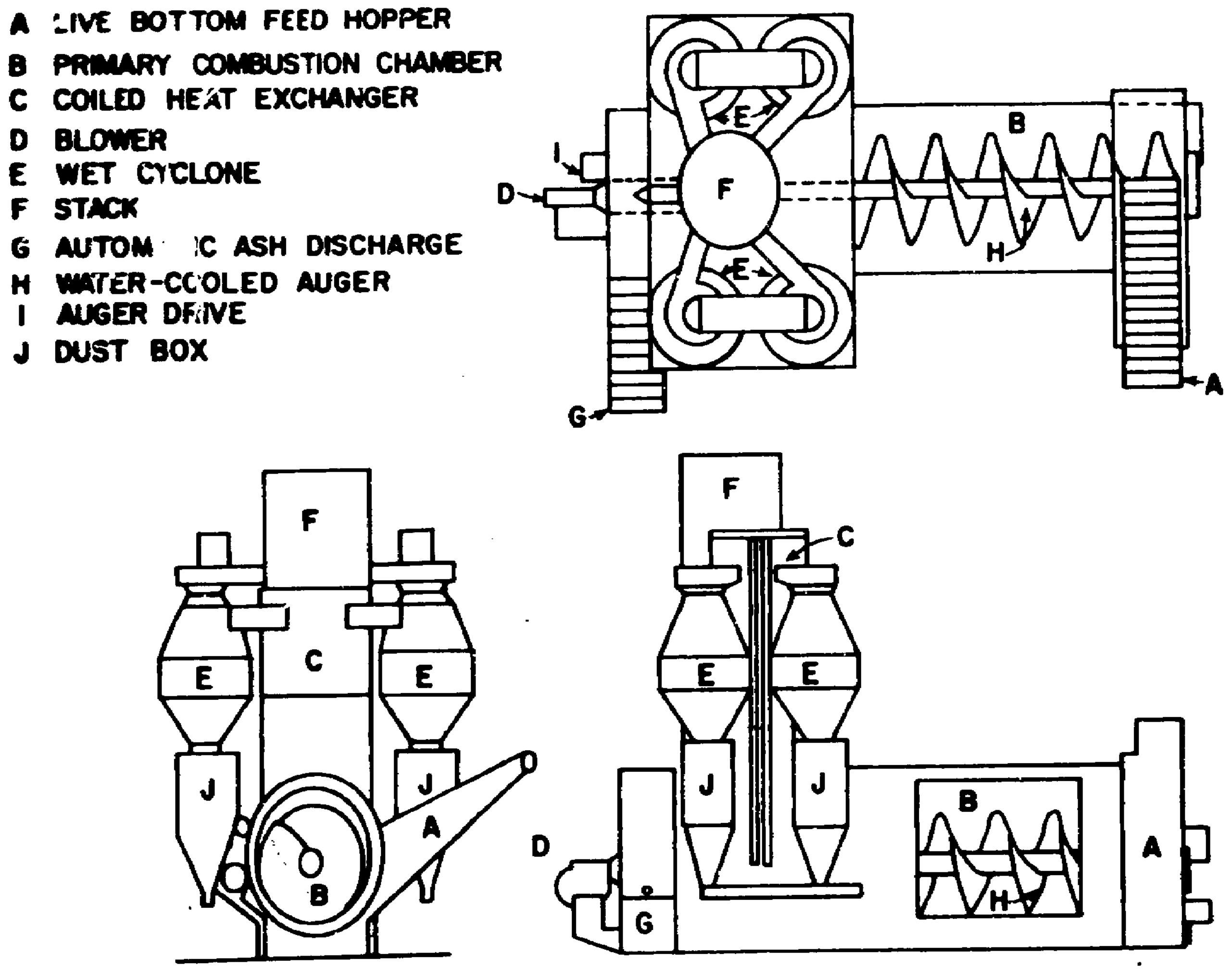


Figure 18. General Operation of Augered Bed Incinerator.

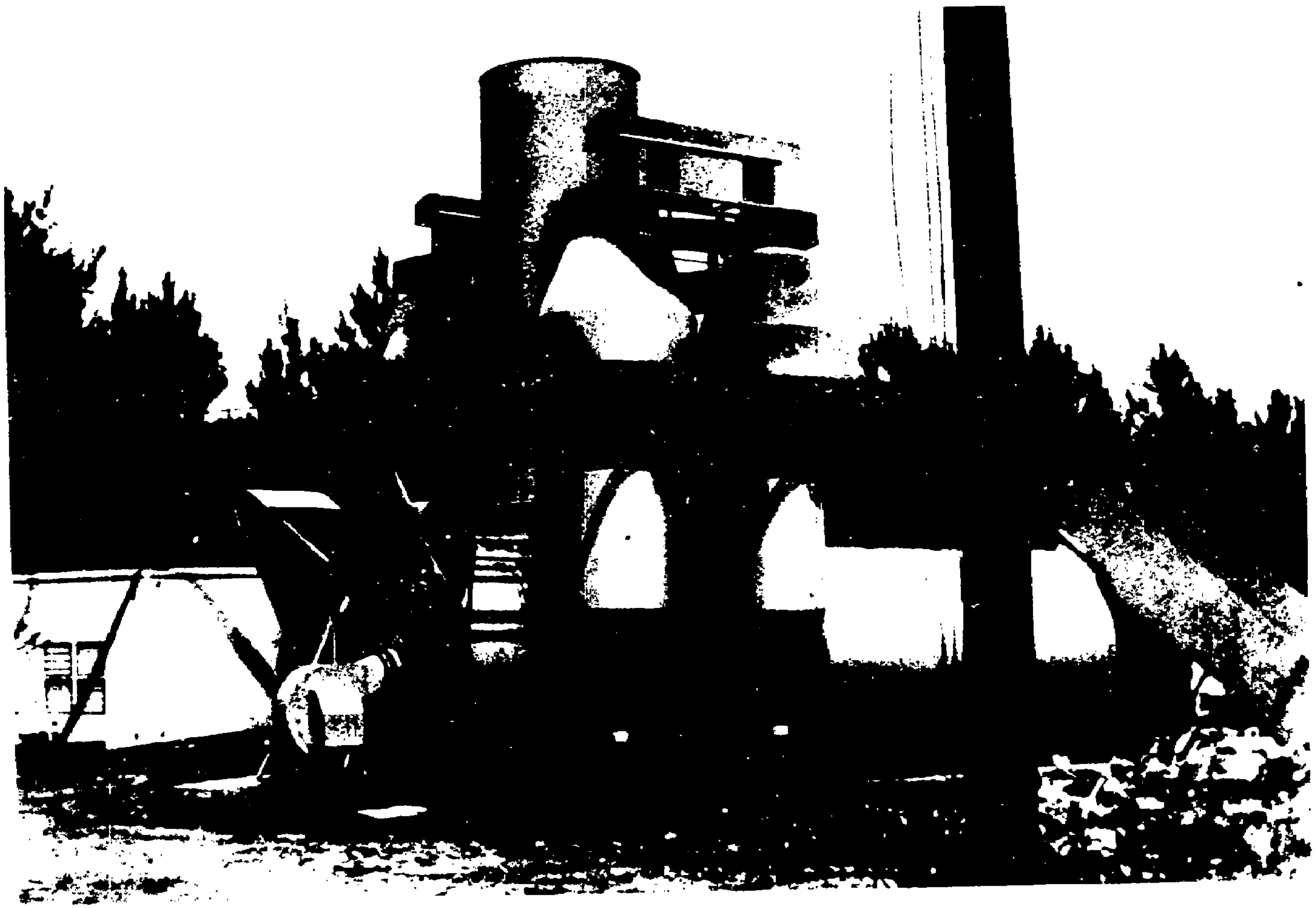


Figure 19. Augered Bed Incinerator.

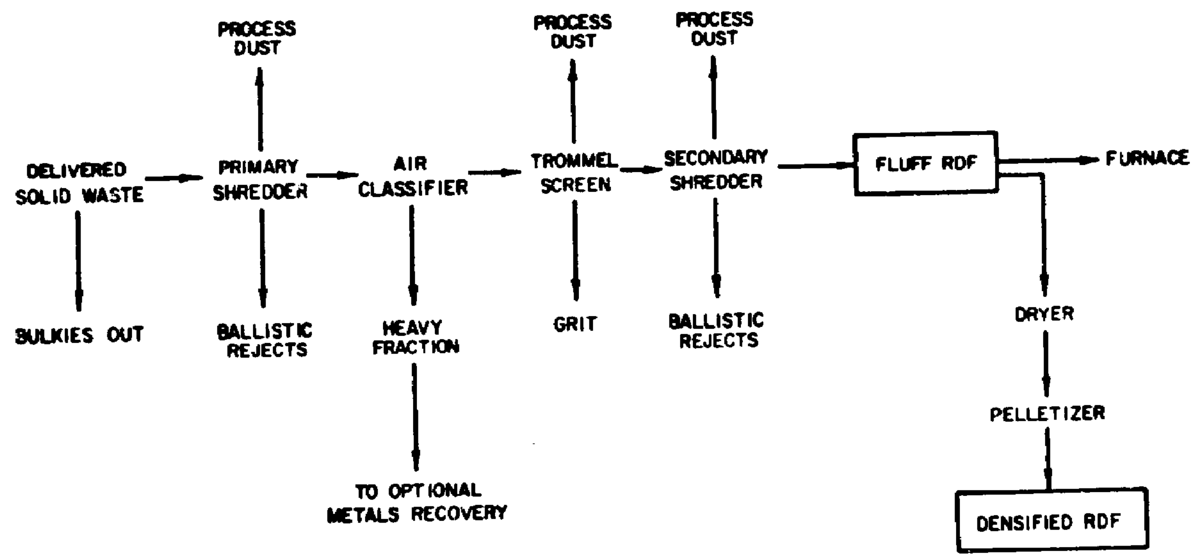


Figure 20. Process Flow for Production of Fluff and Densified RDF. There are as many ways to produce RDF as there are individuals interested in producing it.

Figure 21. Predensified Fluff RDF.

Figure 22. Densified RDF. Mechanical ring type extrusion mill is most widespread equipment for pelleting. Note pellets easily break apart where noncohesive rigid plastics are present.

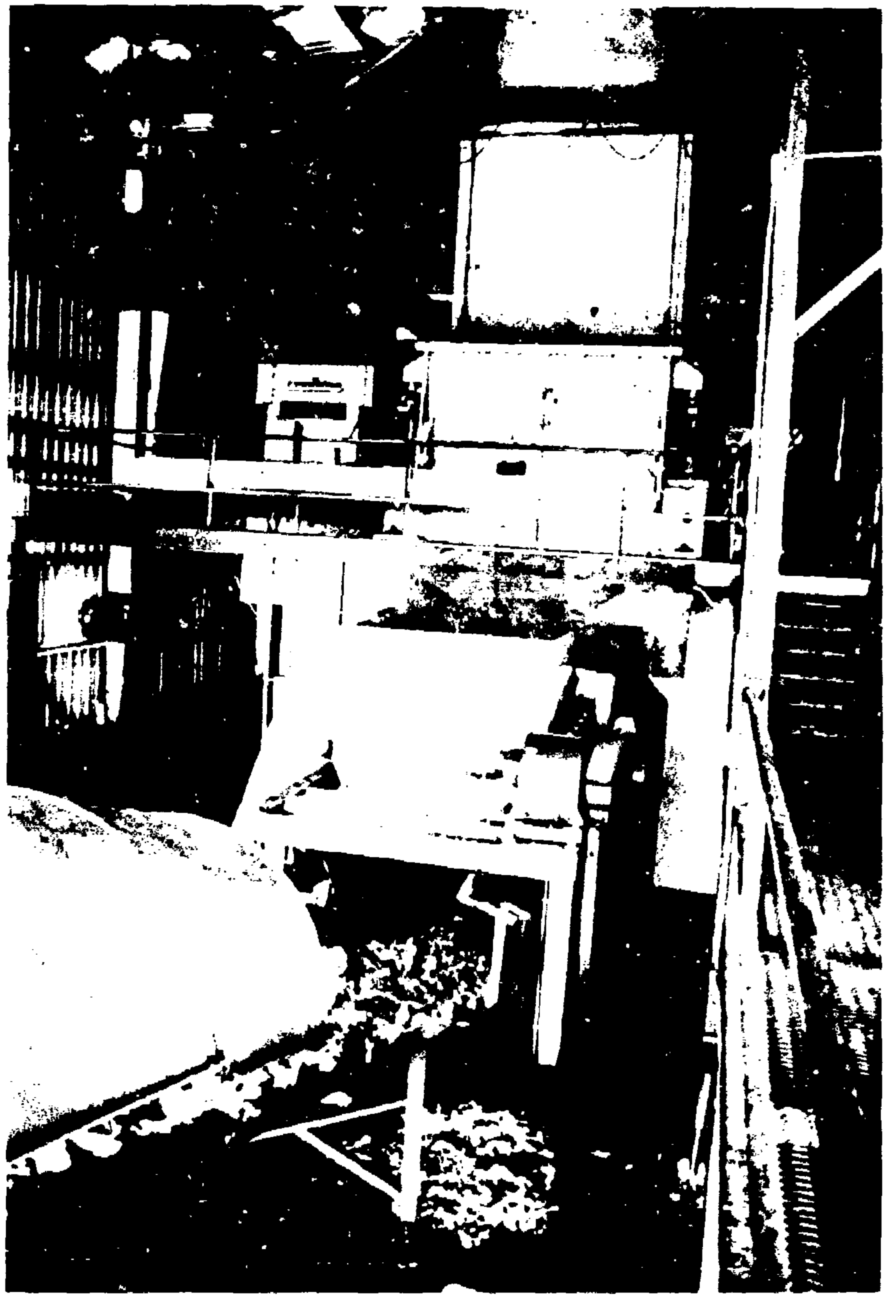


Figure 23. Result of Underdesigning Belt Conveyor After Primary Shredder. Materials handling is widespread problem in waste processing plants.

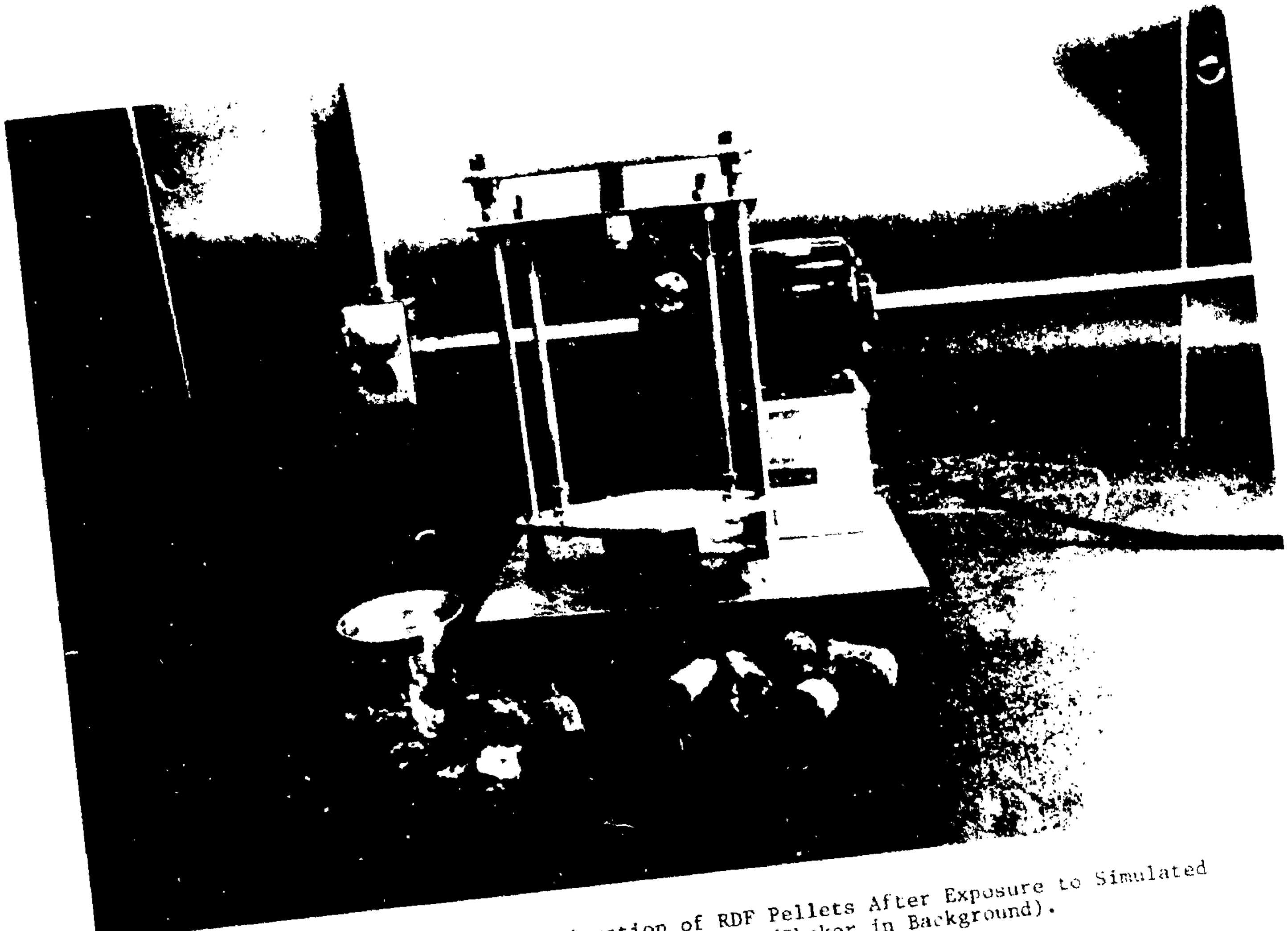


Figure 24. Structural Deterioration of RDF Pellets After Exposure to Simulated Coal Handling System Vibrations (Shaker in Background).

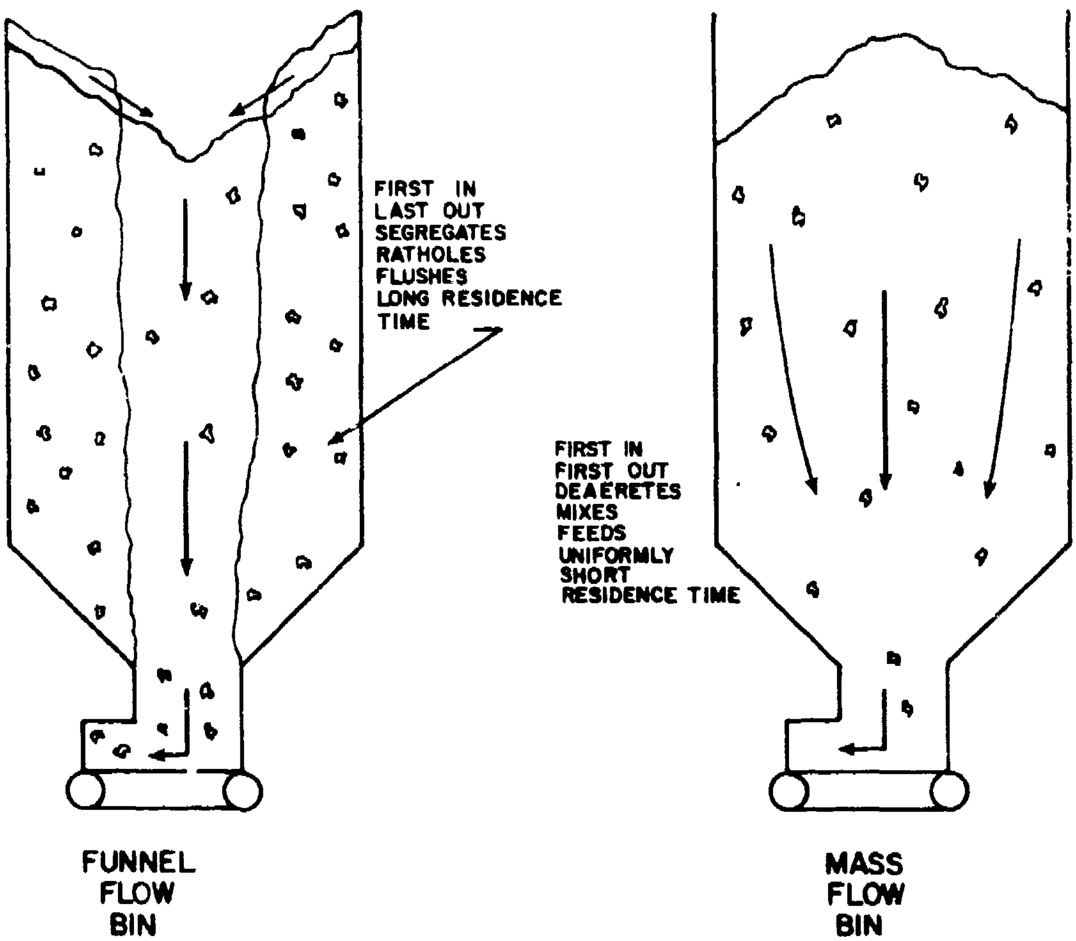


Figure 25. Because of Its Properties, Pelletized RDF Will Not Generally Exhibit Gravity Mass Flow from Existing Coal Storage Bunkers.

Figure 26. Funnel Flow in Coal Bunker. Rathole in DRDF measures 6 ft in width.

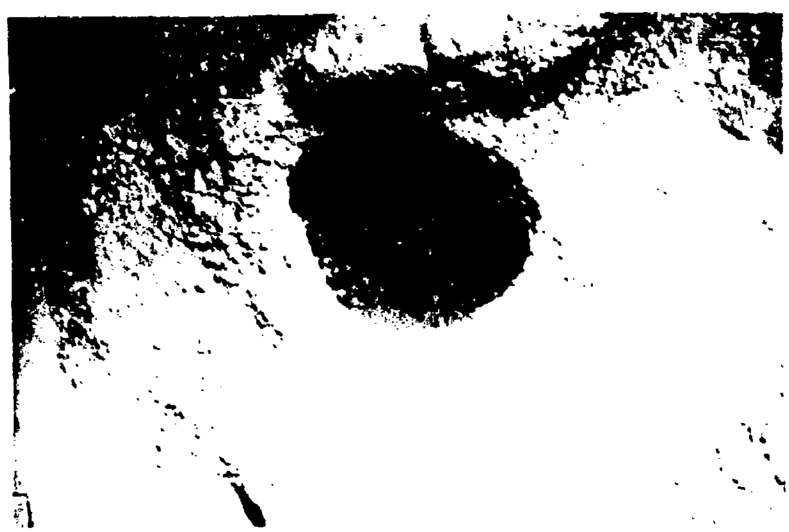


Figure 27. Top View of DRDF Rathole Shown in Figure 26. Depth is approximately 12 ft. Hopper outlet is visible below rathole. Outlet measures 2 ft x 2 ft.

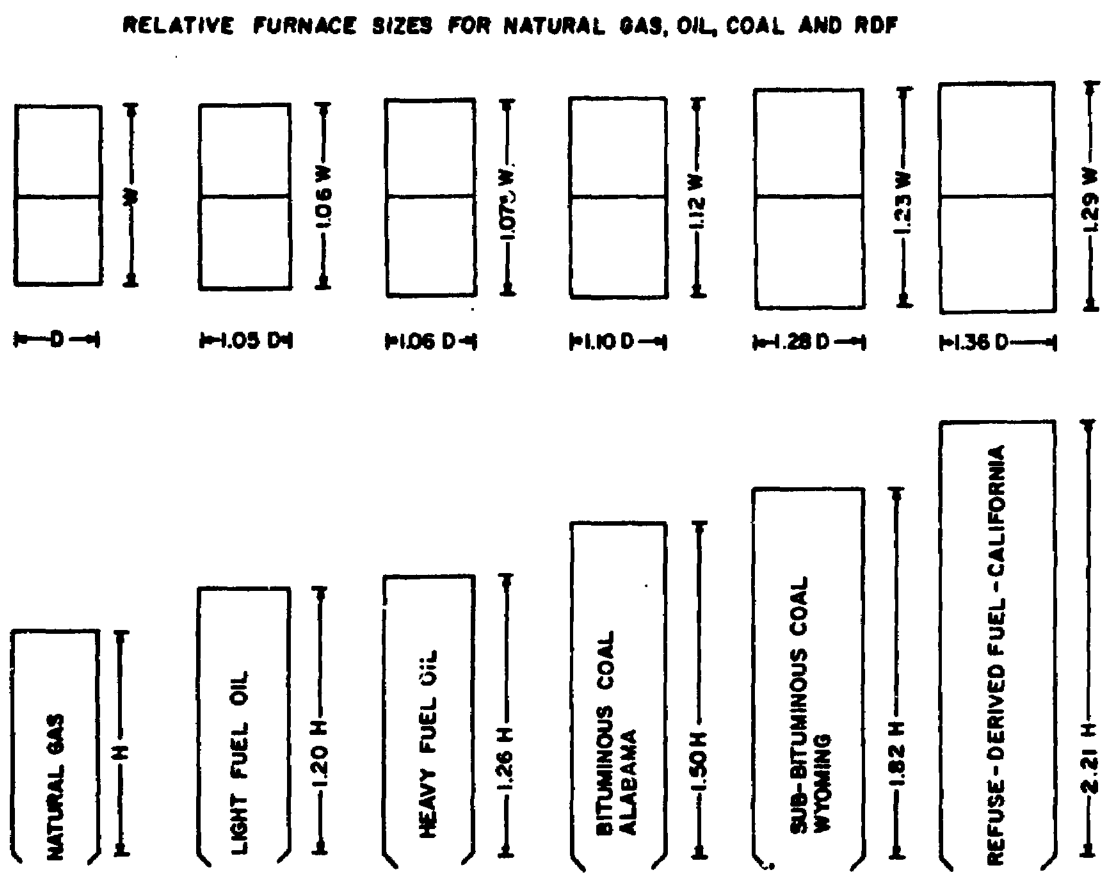


Figure 28. Relative Furnace Sizes for Progressively "Worse" Fuel at Constant Steam Rating. Figure is based on suspension firing to permit including gaseous and liquid fuels.

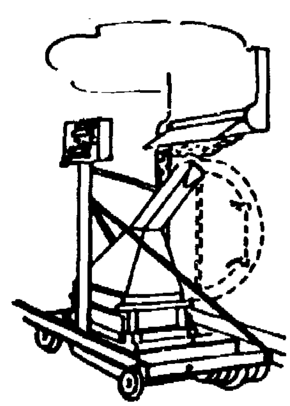


Figure 29. Conventional Weigh Larry. It is improbable that DRDF will reliably flow through this constricting vessel.

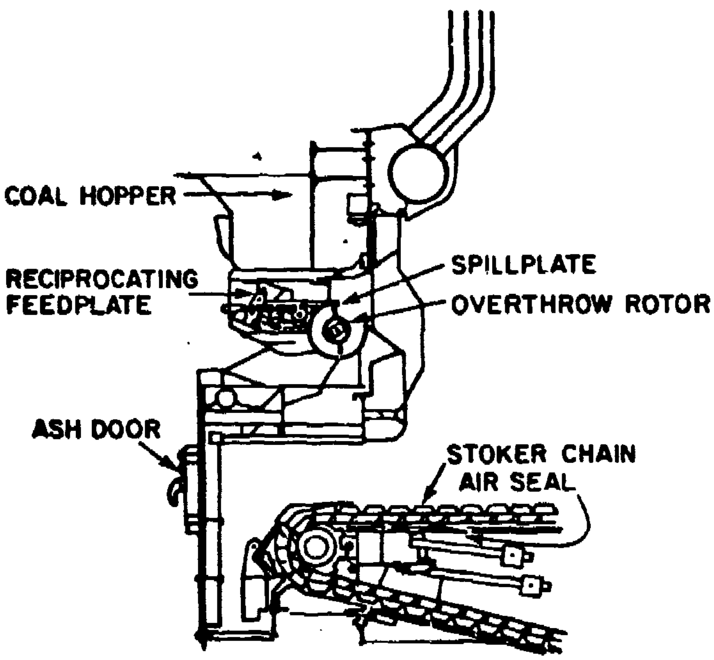


Figure 30. Standard Mechanical Feeder for Spreader Stoker. Flow problems may be anticipated in coal feed hopper. There is potential jamup problem in rotor area if DRDF degenerates.

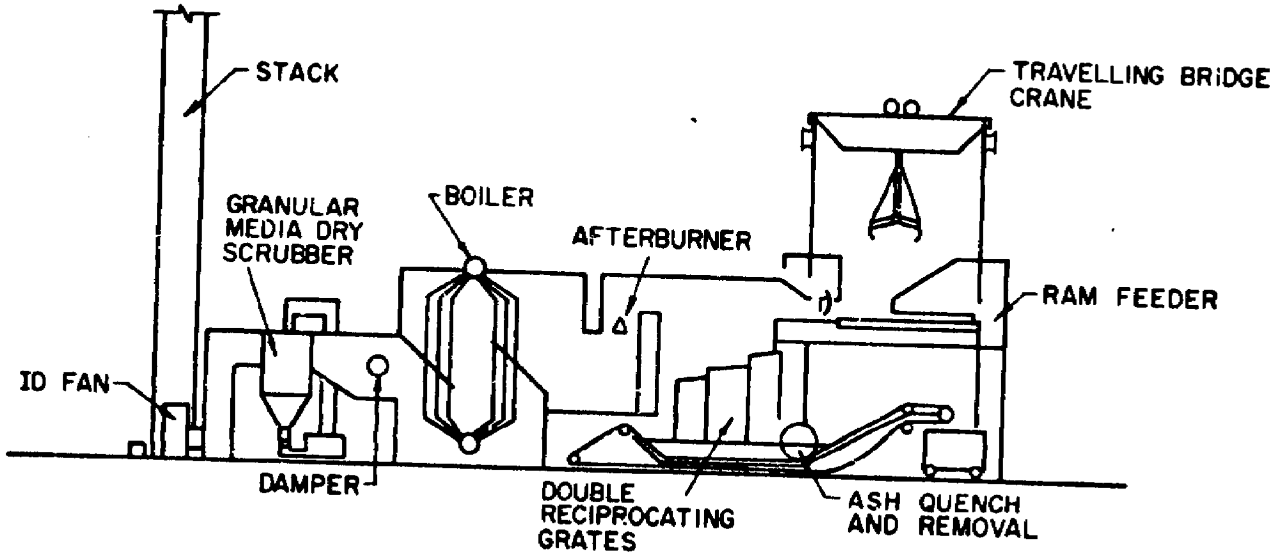


Figure 31. Example of Field Erected Waste Incinerator with Heat Recovery Boiler.

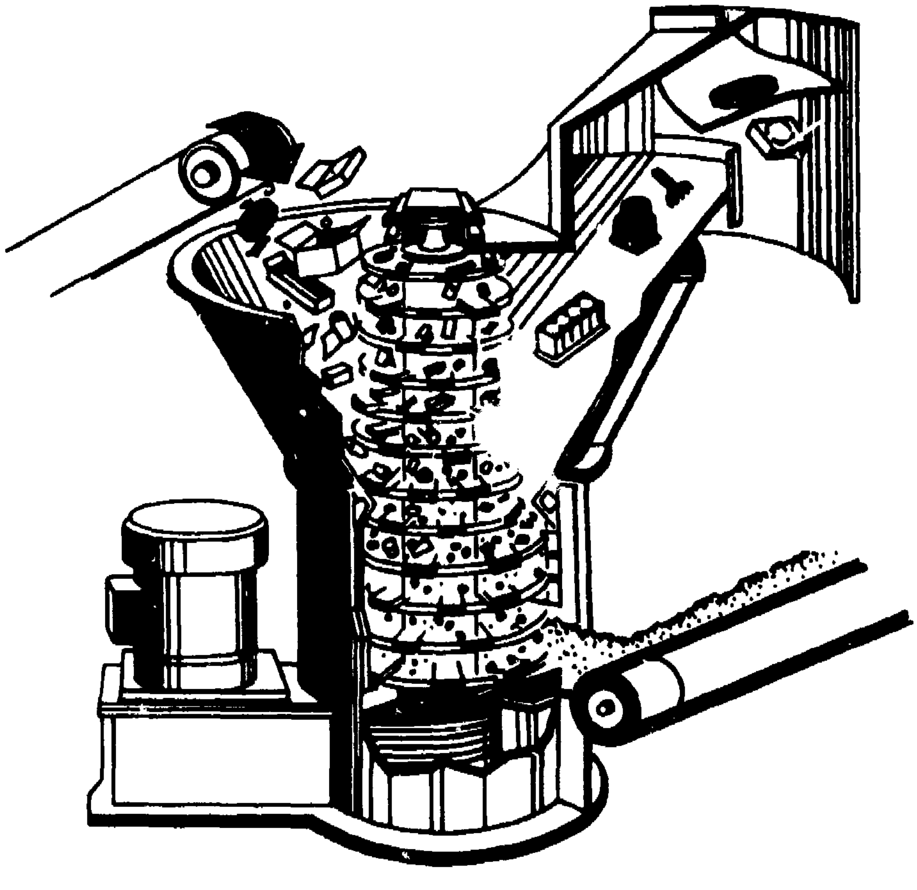


Figure 32. Operation of Vertical Shaft Hammermill. Ballistic rejects pass through rubber curtained chute.

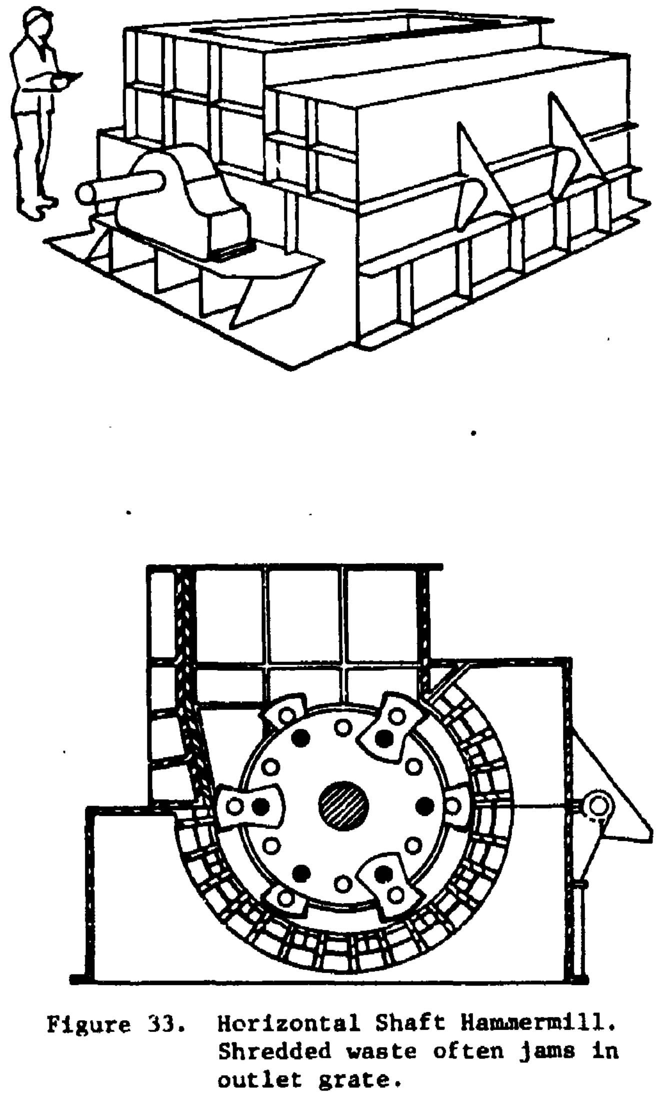


Figure 33. Horizontal Shaft Hammermill. Shredded waste often jams in outlet grate.

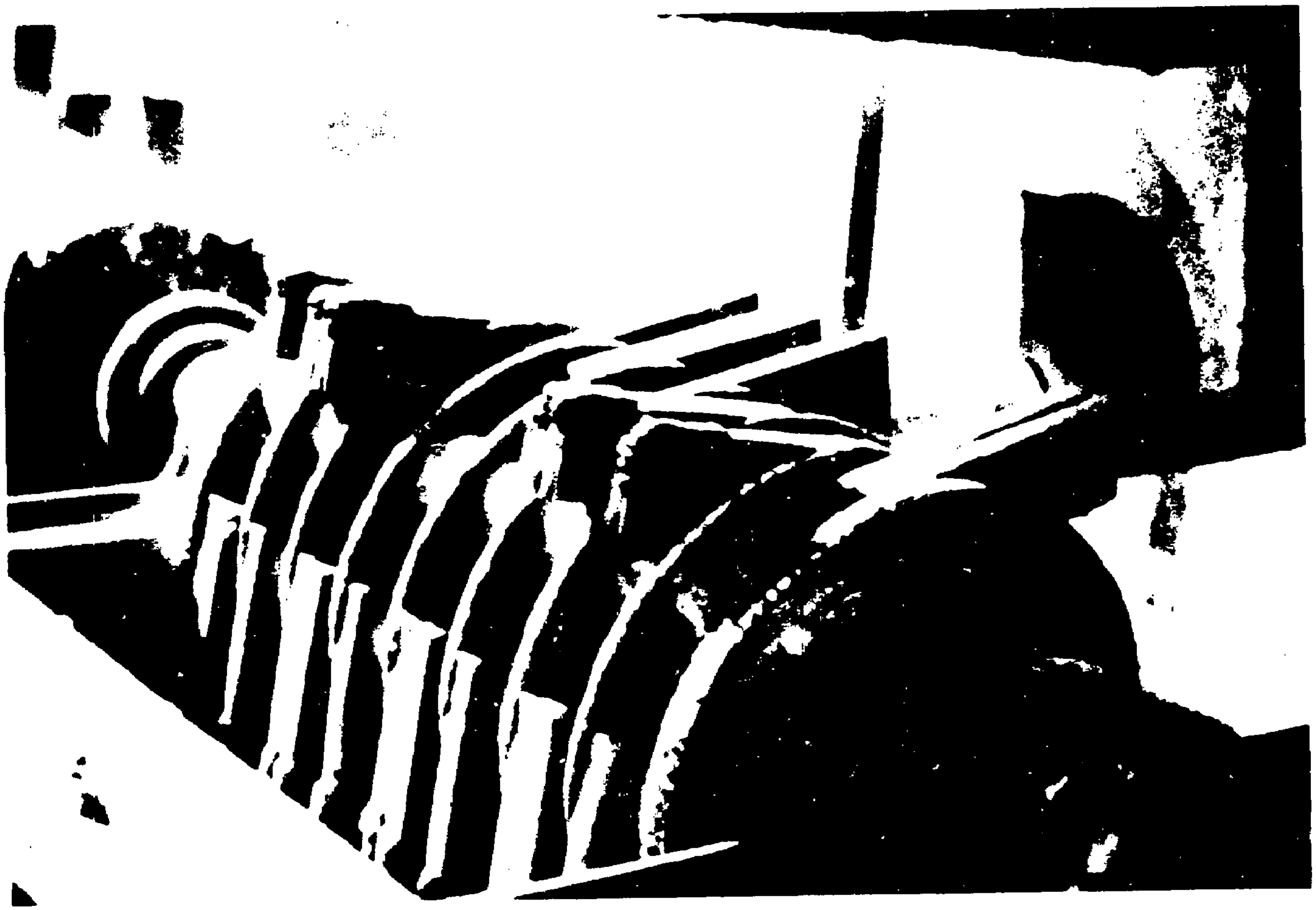


Figure 34. Horizontal Shaft Hammermill. Tip rewelding on hammers must usually be done daily.

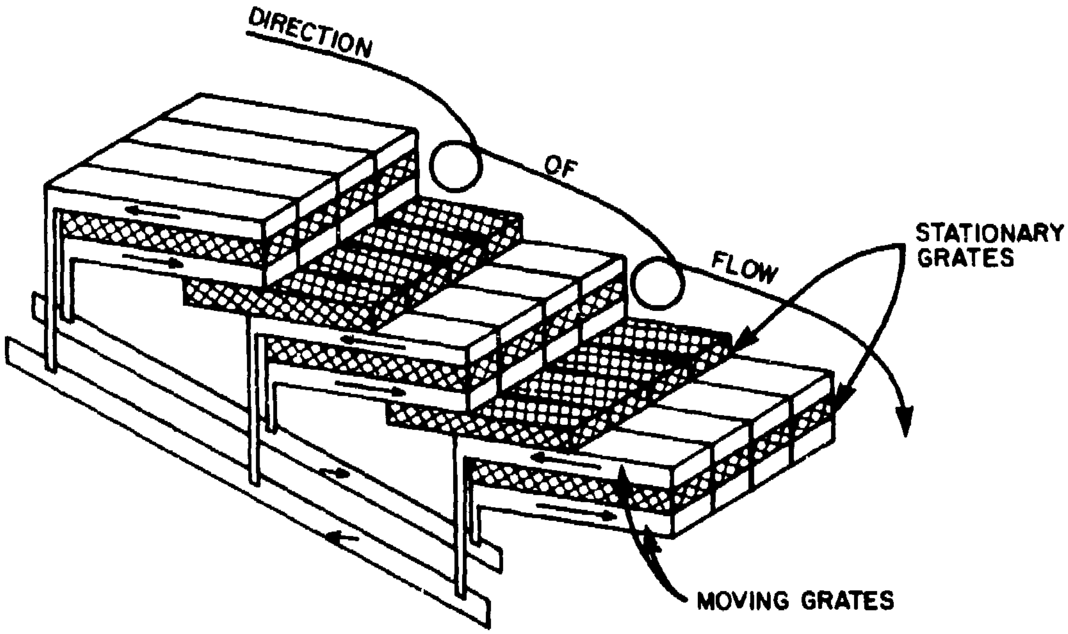


Figure 35. Double Reciprocating Grate Stoker.

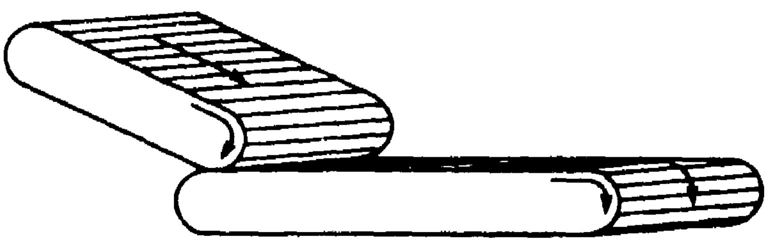


Figure 36. Conventional Traveling Grate Stoker. Because of burnout, grate bar replacement may be necessary as frequently as once/week.

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